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Preliminary Experience With a Stereoscopic Video System in a Remotely Piloted Aircraft Application

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INTRODUCTION

As aircraft systems escalate in performance, complexity, and cost, the need for low-cost, low-risk test procedures becomes imperative. In most cases, flight safety prohibits extensive cost reduction and the presence of a human pilot demands the most stringent precautions. One answer to many of these problems is the use of remotely piloted vehicles (RPVs) to perform high-risk flight testing. This paper discusses some limited experiences with one of the visual systems evaluated for possible use in RPV systems.

Prior to 1969, flight-stress physiology studies at the NASA Dryden Flight Research Center had shown that elevated heart rates were associated consistently with mission responsibility. This addition occurred whether the pilot was in the aircraft flying, or just riding, or was on the ground acting as mission controller, even though physical conditions in each case were undemanding (ref. 1). This was not necessarily true in a simulator. Even when the pilot was overloaded with tasks and with personal performance gains at an apparent maximum, his heart rate never reached the levels seen in similar live flights. RPVs were seen as a way to resolve the question of personal concern being the operant factor in elevated heart rates during flight. Consequently, a primitive RPV system was built (fig. 1), utilizing a cockpit that was designed in-house, commercially available avionics and telemetry, and DFRC's Piper Twin Comanche aircraft (fig. 2).

This original RPV system was inadequate in providing the pilot with displays. There was no direct visual contact with the outside world. The pilot's displays were limited to airspeed, altitude, and horizontal situation indicators. There was no computational capability, either uplink or downlink. Pilot controls were limited to stick and rudder pedals with neither aural nor proprioceptive feedback. The system performed well for all its limitations during early checkout flights, but the RPV pilot reported that the task was demanding and workload during approaches was extremely high. There were no actual landings during these preliminary flights.

Concurrent with the development of this RPEX (Remote Pilot EXperiments) cockpit other divisions at the DFRC had developed remote flight-test techniques based upon model-aircraft radio controls. With direct visual observation of the vehicle, they had demonstrated the efficacy of a pilot in active control during remote testing (ref. 2). The integration of these two techniques was a logical extrapolation and work was begun on what was to become the Remotely Piloted Research Vehicle (ref. 3). The PA-30 became the test bed for development of instrumentation and flight procedures which would be used on all subsequent RPRVs.

From the beginning of this program, it was expected that workload would decrease as soon as the pilot was given live visual contact with the outside, especially during the approach and landing. Instead, the pilots reported that workload was still very high, although they felt more at ease with the visual information than without. A research program was initiated to determine the best video system for RPRV use. The first phase of this program simultaneously developed the training and procedures necessary to land an RPRV using televison as well as the minimum television characteristics for this task (ref. 4). Adequate performance was achieved and the techniques developed were put to effective use on a stall/spin program utilizing a 3/8-scale model of the F-15 aircraft. Workload was still quite high and several concerns remained.

Among these were difficulty in recognizing ballooning due to over-rotation, and the need to use ground details such as runway texture and adjacent tire marks to judge height during landing. The former appeared to be a condition of the narrow field of view (FOV) characteristics of normal video systems. There were approach situations in which the horizon could not be seen and landing situations in which the runway was lost to view. With a vehicle requiring a steep flare, it was possible to lose sight of both the runway and the horizon.

A suggested solution to the height estimation problem was the use of a stereoscopic video. A similar approach had been considered for use with the remote manipulator arm of the Space Shuttle. A commercial system was impractical because of the limited viewing area, but it was feasible in a single operator situation. DFRC was able to obtain a prototype stereoscopic video system very similar in design to the one which had been proposed for the Shuttle experiments. Although funding constraints and equipment difficulties precluded completion of the program, valuable flight experience with this type of video system was gained.

TEST AIRCRAFT AND AIRBORNE EQUIPMENT

The test aircraft is a Piper Twin Comanche, the PA-30, with fully implemented up- and downlink telemetry systems and a single-channel video downlink. Details of the aircraft and the control and instrumentation subsystems have been described in NASA TP-1171 (ref. 4). Although this vehicle is capable of full RPV operation, it is always flown with an onboard safety pilot. Only the equipment specific to the stereoscopic video system is covered in this report. Since normal human binocular vision becomes ineffective beyond 6 m (ref. 5), this system was seen as an opportunity to extend that binocular vision by hundreds of meters to where it would become effective in the landing situation. Consequently, a horizontal mounting rail was built and installed atop the PA-30 aircraft, immediately above the cockpit (fig. 2). This rail was long enough to allow an interocular separation of a maximum of 140 cm. Theoretically, 25-mm focal length lenses at that spacing would allow differentiation of objects 7 m apart at a distance of 100 m.

The cameras themselves were standard COHU models 4510-012 with identical 25-mm focal length lenses. They were contained within cylindrical environment-resistant housings that included the lenses. These housings were mounted on the external rail, and the spacing and convergence angles were set for a given test flight. Because the two images had to be able to be converged by normal human vision, alignment was critical. A special target was constructed so that both cameras could view it when the aircraft was on the ground. The tail of the aicraft was raised to compensate for the difference between the longitudinal attitude of the aircraft during approach and after rolling to a stop. The cameras were then adjusted vertically and horizontally within their mounts without disturbing the convergence angle or separation.

The bandwidth of the existing C-band video telemetry system was too narrow to transmit two separate signals and cost constraints prohibited adding another complete system. A form of multiplexing was chosen to accomplish transmission of the two image signals. A method of constant frequency offset was employed to maintain signal lock. Although this method was the least complicated, it still required exact synchronization of the two camera sweeps. It was also costly to implement. Consequently, one camera was modified to act as a slave and obtain its sweep sychronization signal from the other.

This system was effective in reducing weight and power requirements in the aircraft and enabled two complete video signals to be transmitted within the bandwidth of the existing airborne transmitter. However, it also proved to be the source of a problem which degraded the results of this experiment. The demultiplexer could not separate the signals as effectively as the multiplexer could combine them. Consequently, the final images presented to the operator contained negative ghosts, especially of vertical parallel lines such as the runway. Under this multiplexing scheme, the problem was unresolvable, at least within the funding constraints that existed.

GROUND EQUIPMENT

In addition to the RPV systems described in reference 4, a typical RPV cockpit was used for all of the PA-30 flights. This cockpit (fig. 3), usually used for PA-30 flights, was not unique to this aircraft, and the instrument layout does not duplicate any specific vehicle. All normal control functions were performed for these flights, and all standard instrumentation was present. The information presented was telemetered from the vehicle in flight and represented true flight conditions. For the stereo TV flights, the small monitors which normally presented a single (monoscopic) forward FOV and a separate view of the ground-track plot board were replaced with the stereo display system.

This display (figs. 4 and 5) was fabricated by the contractor who designed and built the accompanying multiplexer-demultiplexer system. The display consisted of two CONRAC monochrome video monitors with the controls mounted external to the stereo system enclosure. Two signals, which might be hardwired from two separate cameras or from the demultiplexer, were presented to these monitors. The resultant images were turned 180° by a series of front-surface mirrors and projection lenses and projected onto a fresnel screen, which acts as a field lens and forms a separate exit pupil for each image.

This concept has numerous advantages over other possible stereo displays. Since the fresnel lens collects light over a large field and concentrates it at the exit pupils, image illumination is optimized. Comfort in viewing is enhanced because the apparent FOV is greater than those of other systems. For the intended use in RPV systems, the lack of glasses or other viewing aids is important. Refocusing of the eyes is not necessary and peripheral displays and instruments may be viewed easily and naturally. Resolution is not affected and the system may be readily converted to color. Finally, the system is mechanically easy to build and can be packaged more compactly than other candidates.

The major disadvantage of the fresnel projection system is a restriction of available head movement. The optical design of the system defines an exit pupil volume of 3.3 cm horizontal, 7.6 cm vertical, and 15.2 cm forward. Visual information is perceived in a realistic manner, with one unexpected anomaly, as long as the eyes are within this volume. The effect is that of direct viewing out of a window the size of the fresnel screen. Although some operators felt that this had a tendency to enhance the "porthole" effect characteristic of video teleoperator visual systems (ref. 6), no one felt that this particular effect interfered with operation.

FLIGHT EXPERIMENT DESCRIPTION

As a measure of the performance characteristics of the system, touchdown dispersion was selected as the major parameter. The flights were to be made on one of the

Muroc dry lakebed runways at Edwards Air Force Base. This runway was chosen for the direct line of sight between it and the antenna complex which was to receive the telemetry signals. The video signal was especially susceptible to dropouts due to ground effects and building interposition; thus, it would occasionally affect the controls link and cause a loss of RPV control. The onboard safety pilot could recover the aircraft, but such signal interference would have caused intolerable data problems To achieve repeatability and simplify operations, the pilots were directed to fly a "racetrack" pattern around the runway. The runway had been marked with a series of distance indicators and a desired touchdown point (fig. 6). A film record of each approach and landing was made to determine the point of touchdown.

At this point in the program, equipment problems began occurring with increasing frequency. The major impact was in the camera and multiplexing subsystem. The master/slave synchronization system was unreliable and repeatedly failed in an unpredictable manner. Many attempts were made to obtain data flights but the cameras would invariably drift enough to preclude more than one or two reliable landings per flight. In addition, the multiplexing system was never able to adequately separate the two signals, resulting in the distracting false images mentioned earlier. These ghosted images were present but very faint when the system was hardwired together in the lab. The problem appeared to originate as an artifact of the chosen multiplexing scheme. The fact that the ghosting problem was not as severe in the lab indicated that the transmission system was somehow compounding the problem. It is possible that a stronger broadcast signal of wider bandwidth would have solved some of the ghosting problem. Whether or not the multiplexing problem could have been resolved is a moot point since the camera repair became the primary difficulty. After repeated returns to the manufacturer for correction, the delays caused by these malfunctions finally forced a management decision to terminate the program.

FLIGHT EXPERIENCES

Despite the hardware difficulties, several test flights were made before the program ended. Although no qualitative data were taken, valuable flight experience was gained with this unconventional video system. Four flights were made with the three test pilots who were trained as RPV pilots. All portions of the system were exercised, including the point of touchdown filming. These data were reviewed in their original form, but the few touchdown points actually recorded were not extracted from the film frames since the visual system was never judged adequate for accurate testing. Summaries of the flights are presented below.

Flight 1

Flight 1 was a complete system exercise flight to test all components under operational conditions. Dryden's most experienced RPV test pilot was at the ground controls. The overall video signal became marginal shortly after takeoff, and the second approach was brought to a full stop on the lakebed. The difficulty, caused by a weak battery, was easily corrected. Flight tests in continuous RPV mode for 26 min provided five satisfactory landings. Such a long time in RPV mode was found to cause system drift that appeared as control offsets and forced the pilot to compensate continually. Even though takeoffs and landings were possible, control was switched to safety pilot immediately after touchdown and returned to RPV pilot just before the downwind turn. This allowed for system reset.

In general, the 11 touchdowns made on this flight were satisfactory. The equipment problems that were encountered proved to be minor compared to the problems discovered by the RPV pilot. The RPV pilot found the system to be more work to use and the image degraded relative to the monoscopic video. However, he did not experience any eye fatigue. Because of the low altitudes at which testing was conducted, the video system was prone to multipath imaging. The pilot commented that it was difficult to judge the height or size of objects.

Flight 2

Flight 2 was to have been the first flight for data; thus, the pilot took many practice approaches without touchdown and left the landing gear extended. This placed him in RPV mode for 22 min, which confirmed the previously observed system drift. After two successful and smooth landings, the pilot reported double vision and had to close one eye to land monoscopically. This raised the possibilty of exophoria, but two more attempts at landing made it obvious that it was a system failure. An impedance-matching amplifier had become intermittent, occasionally sending both signals to both monitors. The pilot felt that he was able to judge height on approach but poor resolution made size discrimination difficult.

Flight 3

Only four touchdowns were made on this flight because of equipment problems. There was severe image degradation as a result of multipath transmission, noise bars, and signal breakup. The signal emitted from the aircraft was marginal in strength because of the multiplexing. The only available improvement was a better radiated pattern produced by relocating the aircraft antenna. This resulted in a gain of <0.3 dB. The consensus was that a more powerful transmitter was needed. Resolution and size discrimination continued to be problems. The poor resolution was inherent in the nature of the video system and could not be improved without major changes.

In this flight there were several long periods during which the various equipment problems were treated. While viewing the stereoscopic images as the aircraft passed over a railroad, the program director commented that the overall effect was that of looking through a window at a model railroad diorama. The stereo effect was pronounced wherever there was terrain relief, but absolute object size was ambiguous. He felt that the brain was interpreting the widely separated images as originating at the normal interpupillary separation distance of 75 mm, thus perceiving viewed objects as being much smaller than they actually were. This came to be called the "model railroad effect" and helped explain the size-discrimination problem.

Flight 4

This flight was relatively uneventful. Ten successful approaches and landings were made by a pilot with much overall experience but very little in RPVs. A preflight double image was traced to swapped display leads and corrected, but the "ghost" images caused by synchronization cross-talk became worse. The pilot was able to ignore this and land satisfactorily but the visual system was judged unacceptable and the flight program was terminated until the equipment problems could be rectified. Because of time and money constraints, this was not accomplished.

CONCLUDING REMARKS

Although the program was not completed because of hardware problems and funding constraints, useful experience was gained with the development of a stereo system for remote operation. It was demonstrated that such a system was feasible and that the stereo effect was usable in the RPV mode. Whether it is advantageous remains to be shown, but the effect is pronounced in up-and-away flight.

Comments from all observers on the restricted field of view, which was typical of RPV systems and no worse for this display, indicated that more benefit might be obtained from a system which gave greater field of view and incorporated some of the operator's peripheral vision.

RECOMMENDATIONS

1. The use of stereoscopic video as the visual-information system in the teleoperator situation needs to be explored from a psychophysiological viewpoint in both the laboratory and flight environments.

2. An alternative multiplexing method is necessary if such a system is to be practical in flight. A better but much more expensive solution would be the use of two complete and independent video downlink systems.

3. Although there is no indication that the phenomenon has any detrimental effect on performance, the perception of reduced scale from extended ocular separation is interesting and may have implictions in operator/display interfaces. An extended study of this effect could prove valuable.

4. The utility of the stereoscopic video system needs further exploration in the homogeneous field situation, such as a flat, dry lakebed with no height variation and little color change.

Ames Research Center
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National Aeronautics and Space Administration
Edwards, California, March 10, 1983

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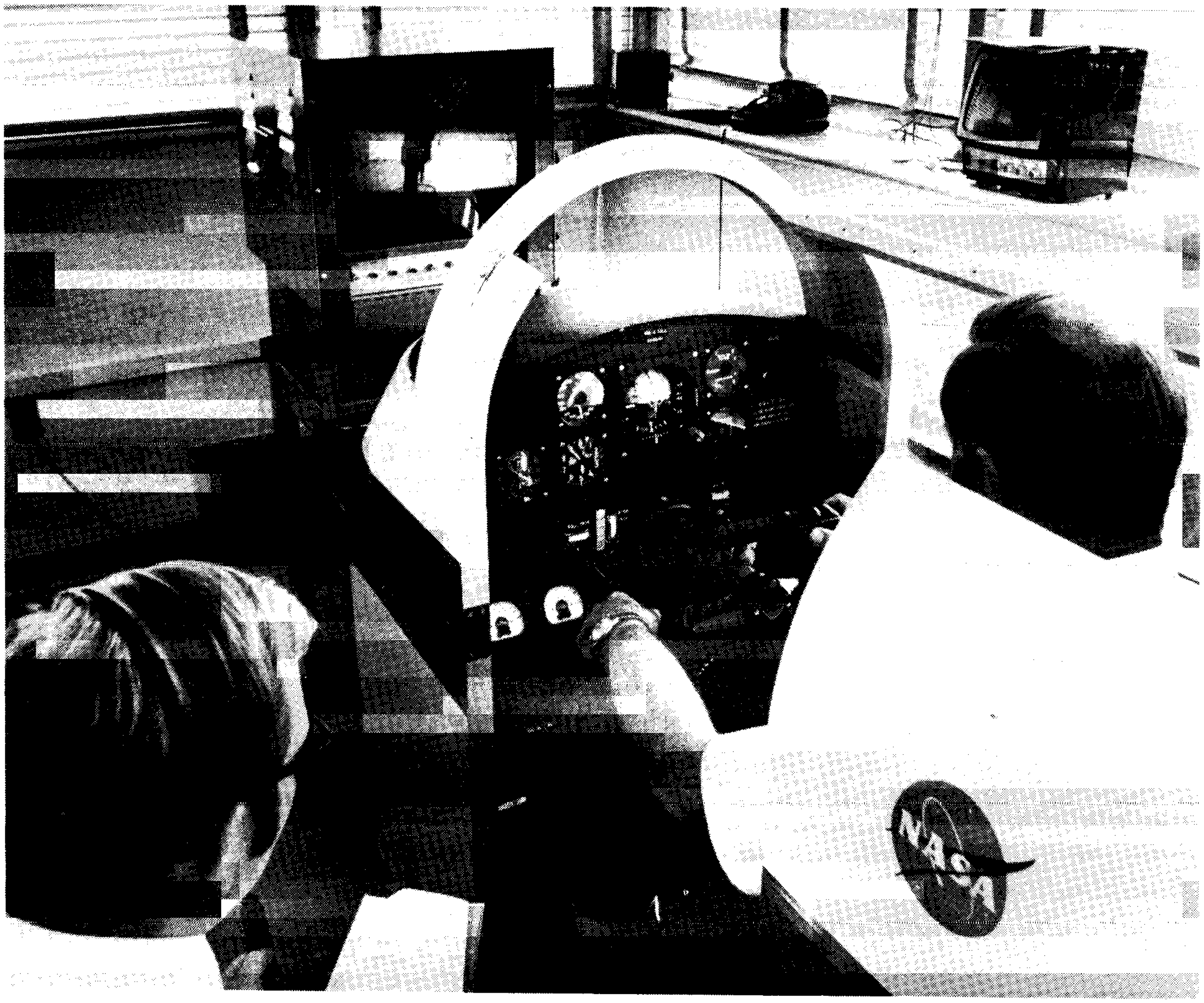

Figure 1. RPEX, the first RPV cockpit at Dryden. Note the video shows the ground plot board. There was no out-the-window video for these early flights.

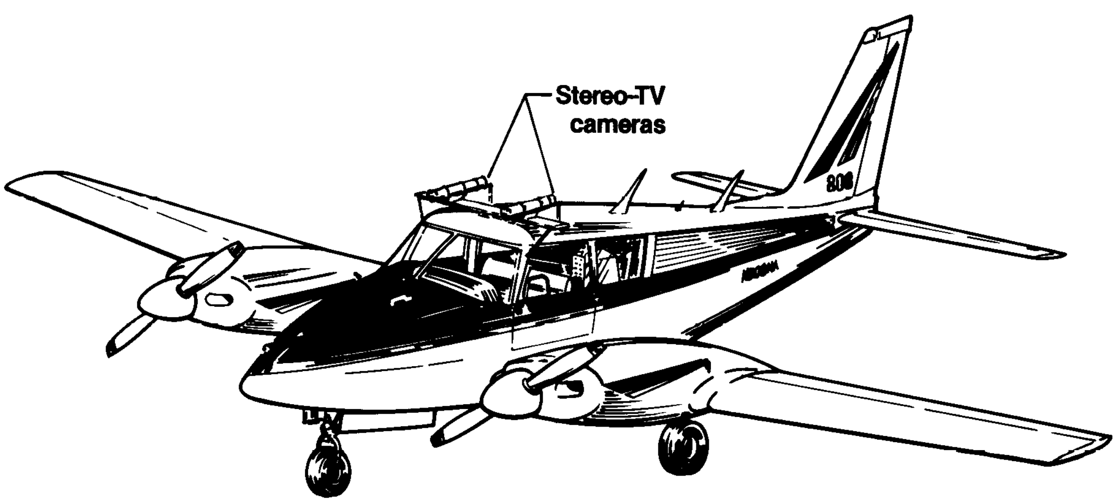

Figure 2. The PA-30, Dryden's RPV-development vehicle, showing the stereo-TV cameras.

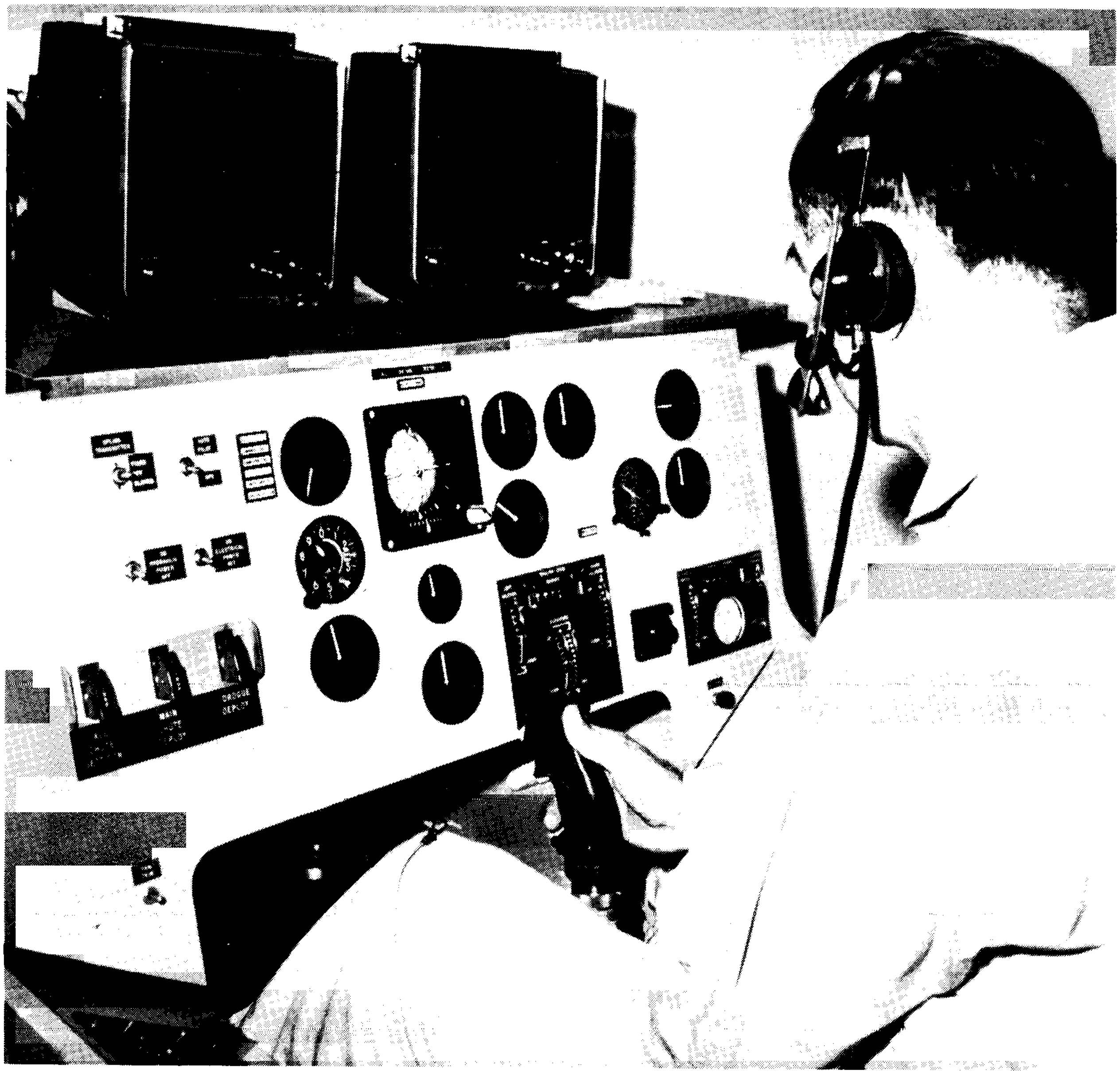

Figure 3. Typical RPV cockpit as used for the PA-30. In this arrangement, the left monitor shows the forward view, and the right monitor shows only the map board.

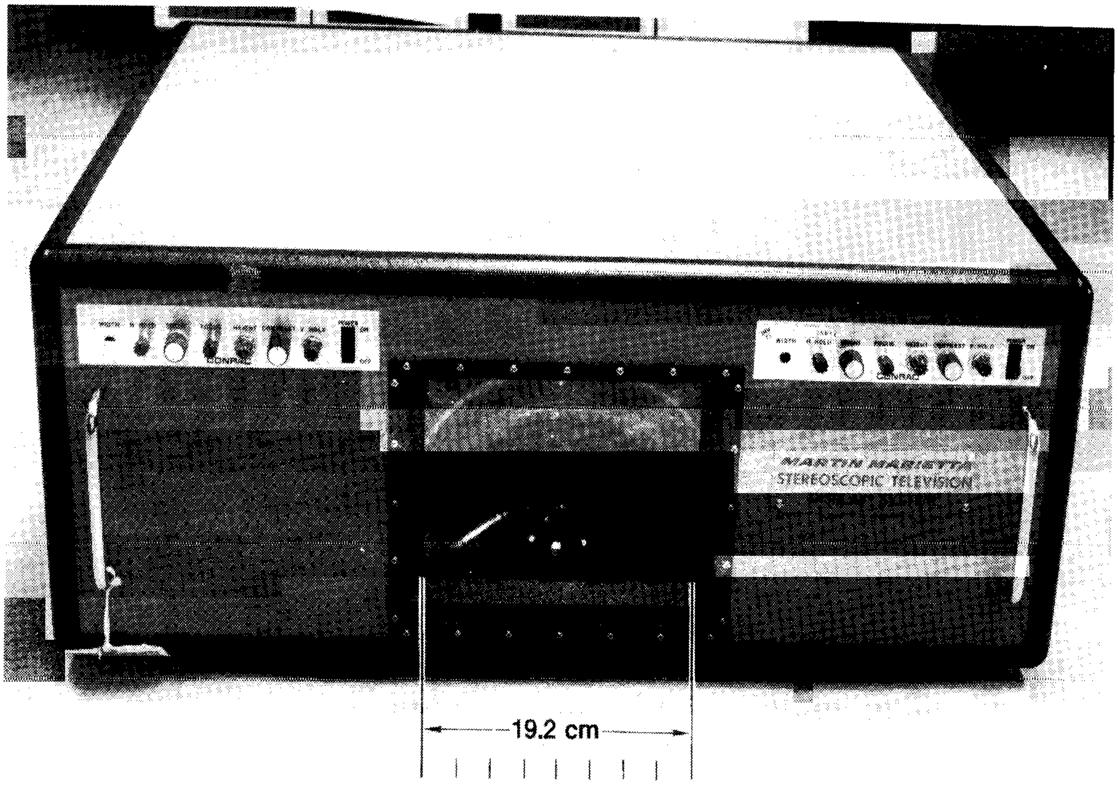

Figure 4. External view of stereo-TV display.

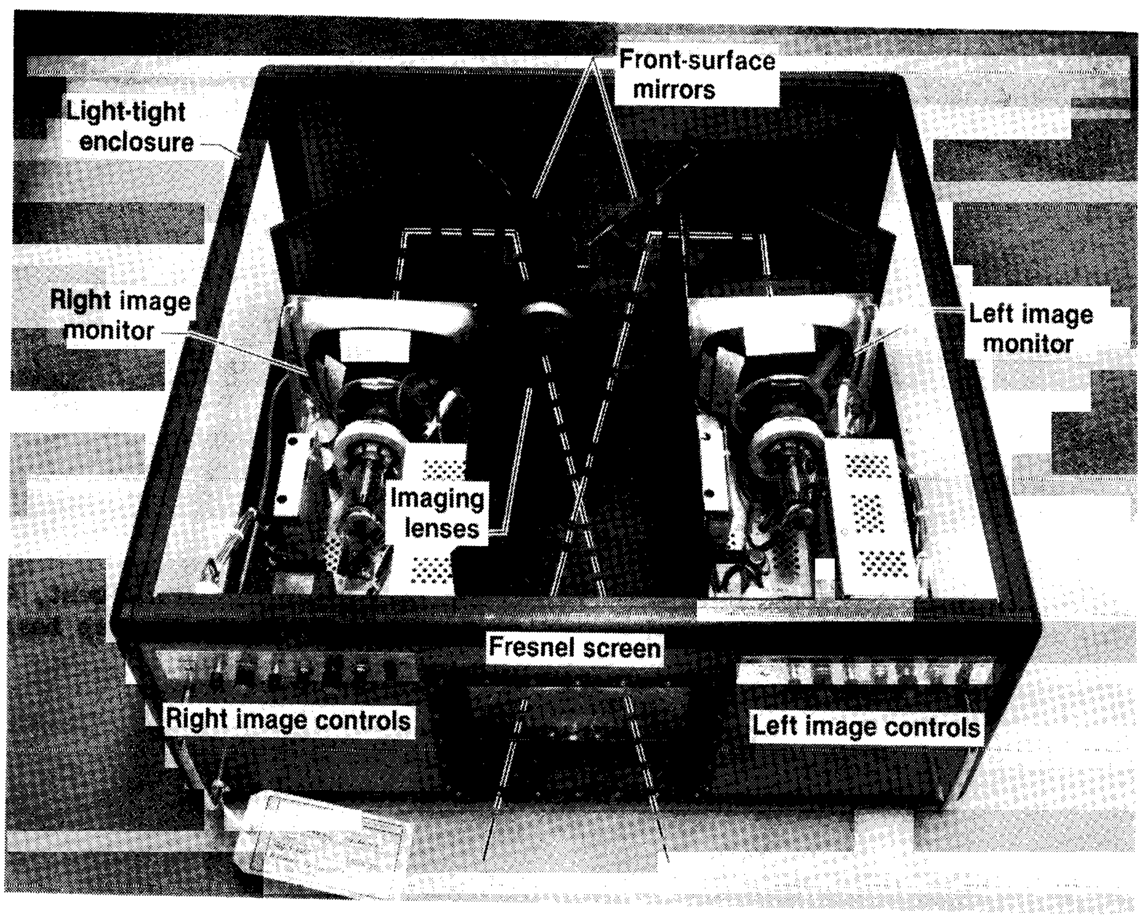

Figure 5. Internal layout of stereo-TV display showing light paths.

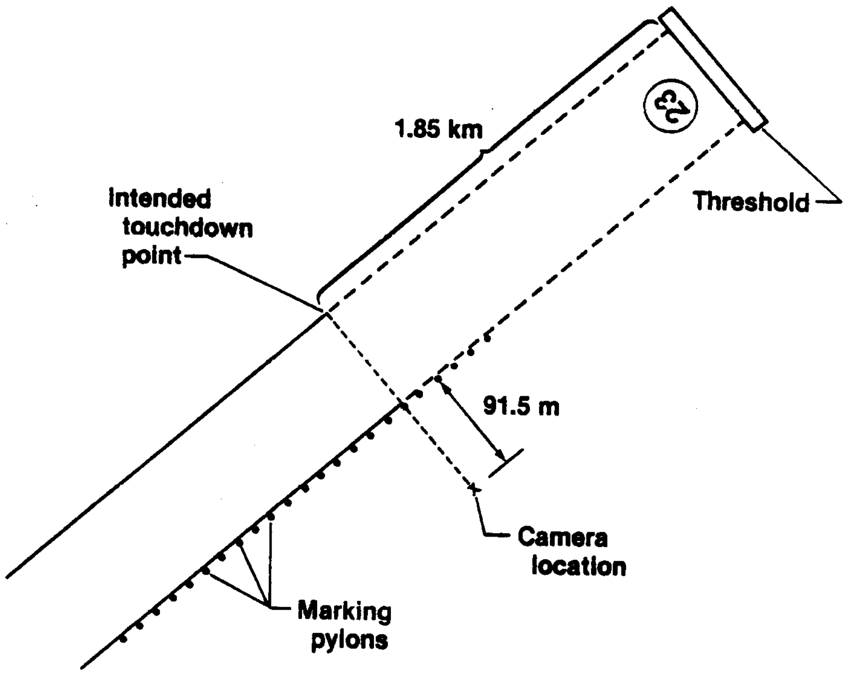

Figure 6. Runway markings and camera location.

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15. Supplementary Notes

16. Abstract

This paper discusses experiences with a stereoscopic video system in a remotely piloted aircraft application. Remote piloting video display development at the Dryden Flight Research Facility of NASA's Ames Research Center is summarized, and the reasons for considering stereo television are presented. Pertinent equipment is described. Limited flight experience is also discussed, along with recommendations for further study.

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